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ESTIMATION OF THE "NON EXHAUST PIPE" PM10 EMISSIONS OF STREETS FOR PRACTICAL TRAFFIC AIR POLLUTION MODELLING

Ingo Düring#, Johannes Jacob§, Achim Lohmeyer#, Martin Lutz* and Wolfgang Reichenbächer*

Lohmeyer Consulting Engineers, Mohrenstraße 14, Radebeul, D

§ Saechsisches Landesamt für Umwelt und Geologie, Radebeul, D

∗ Senatsverwaltung für Stadtentwicklung, Berlin, D

Contact mail: Achim.Lohmeyer@Lohmeyer.de

ABSTRACT

The paper describes procedure and results of a study for Saechs. Landesamt fuer Umwelt und Geologie and for Senatsverwaltung fuer Stadtentwicklung, Berlin. It contains the results of silt load measurements of 2 streets in Germany and PM10 emission factors for these streets, deducted from curb side and background PM10- and NO_x-concentration measurements.

The paper presents a first proposal for Germany for an operational method to determine the "non exhaust pipe" emissions of single streets. It is a modification of the AP-42 model of the US-EPA, using as parameters: location of the street (city/open country), kind of street, traffic load, average weight of a fleet vehicle, yearly number of days with rain and quality of the street surface. It is shown that the quality of the street surface might have significant influence on the PM10 emission and that the modelling is far from being satisfactory.

Keywords: Silt load, emission factor, emission modelling, abrasion, re-suspension

1. INTRODUCTION

EC Council Directive 1999/30/EC sets out limit values for the concentration of PM10 in ambient air. Field measurements show an exceedance of these limit values in the vicinity of streets (Lenschow et al., 2001), thus the problem has to be addressed and the reasons for the exceedances detected. However, PM10 pollution modelling in the vicinity of a paved street is deficient because the understanding and the modelling of the PM10 emissions is vague. For the vehicle fleet in Germany, there is comparatively good information on the contribution coming out of the exhaust pipe, but the quantification of the PM10 emissions resulting from abrasion of vehicle components and especially from the street surface is not satisfactorily solved. A critical examination by Venkatram (2000) of the AP-42 model, published by the US-EPA for paved street emissions, came to the conclusion, that there are lots of open questions.

Therefore a project was launched to proceed in the non exhaust pipe PM10 emission modelling for streets in Germany. The modelling was aimed to be applicable for operational purposes by state and city authorities and consultants and it should be based on easily available input parameters. Therefore the project consisted of the following steps:

- Literature survey for identification of an available model
- Field measurements in a heavily trafficked street canyon in Leipzig and in Berlin to check the performance of the model
- In case of unsatisfactory performance: Set up of a first proposal for possible modifications of the model to improve its performance for use in Germany

2 PROCEDURE

2.1 Literature survey

The only operational models were found to be a model in Sweden (SMHI-model, Bringfeld et al., 1997) and the model of the US-EPA (EPA, 1997). For the EPA model, Rauterberg-Wulff (2000) showed the way it needed to be modified in order to describe the results of field measurements in Frankfurter Allee, Berlin. Landesumweltamt Brandenburg (LUA, 2000) modified it further for application in the State of Brandenburg.

Other countries for example Austria, UK, France were found to determine the PM10 emissions of streets from the exhaust pipe emissions of NO_x, soot or particles or were found to neglect the non-exhaust-pipe emissions.

The survey showed a large uncertainty concerning the PM10 emission of streets by dust re-suspension and abrasion and much complaints about the lack of a decent model were found. The performance of the EPA model is considered not to be suitable by an expert group in the US (Venkatram, 2000), and the UK Airborne Particle Expert Group (APEG, 1999) considers the model not to be applicable in the UK.

Nevertheless, an operational model has to be provided for assessment under the EC Directives. So, in the absence of anything else than the EPA model, this model was used as the basis for the project. The EPA version of the model is

$$e = 0.56(sL)^{0.65}(W)^{1.5}$$

where *sL* is the silt load (PM75) in g/m^2, *W* is the average weight of a vehicle of the fleet in tons and *e* is the PM10 emission in g/VKT for days without rain, VKT means Vehicle Kilometre Travelled. The calculated emission contains all contributions, i.e. exhaust pipe emissions plus emissions by dust re-suspension and abrasion. No emission is supposed to occur during days with rain. Recently, the EPA started a discussion about an update, introducing into the model, that the emission during raining days is half the emission during dry days.

Concerning the importance of the non exhaust pipe emissions it could be derived from PM10 emission data, found in the literature (see later **Tab. 1**), that the total PM10 emission in g/VKT of these streets was up to 4 (or even more) times the exhaust pipe PM emission.

2.2 Field Measurements in Leipzig

From mid October to mid November 2000, field measurements in the street canyon Lützner Strasse in Leipzig were done, including determination of the silt load of the street, traffic counts (passenger cars and trucks), PM10 and PM2.5 concentrations including analysis of the PM components on the filters and PM10 and PM2.5 background concentrations. The findings are:

The PM75 silt load of the street (needed for the application of the EPA model) was 0.16 to 0.25 g/m^2 on the traffic lanes, 1.6 to 2 g/m^2 in 0 to 25 cm distance from the curb, leading to a mean (area weighted) load of 0.38 ± 0.21 g/m^2. This value is about double the value, found by Rauterberg-Wulff (2000) in Berlin, Frankfurter Allee.

Because of the short period of the measurements and unfavourable wind conditions, the confidence in the conclusions is reduced. Nevertheless it shows the total PM10 emissions, determined by inverse dispersion modelling (0.47 to 1.1 g/VKT), to be higher than calculated by the EPA formula (0.37 to 0.84 g/VKT, depending on the silt load applied). On the basis of the German Exhaust Pipe Emission Factor Handbook (INFRAS, 1999), an emission of 0.056 g/VKT is determined, thus the non exhaust pipe contribution is 0.55 to 0.65 g/VKT. So, in this street for that time period, there was roughly a factor of 10 between emission by re-suspension and exhaust pipe. The PM10 concentration measurements are still going on but are not evaluated yet.

This high emission by re-suspension could be caused by the bad condition of the street surface, being very old and cracked, additionally by the heavily silt loaded pedestrian walk-ways and the unpaved parking spaces parallel to the street.

2.3 Field Measurements in Berlin

From mid November to mid December 2000, field measurements in the street canyon Schildhornstrasse in Berlin were done, including determination of the silt load of the street, traffic counts (passenger cars and trucks), PM10, PM2.5 and NO_x concentrations at the street and in the background including analysis of the PM components on the filters at all monitoring stations. The findings are:

The PM75 silt load of the street was 0.06 to 0.14 g/m^2 on the traffic lanes, 1.7 to 2.3 g/m^2 in 0 to 25 cm distance from the curb, leading to a mean load of 0.16 ± 0.09 g/m^2. This value is nearly the same as found by Rauterberg-Wulff (2000) in Berlin, Frankfurter Allee with ca. 0.2 g/m^2. The components of the silt load were found to be ca. 86 % mineral components, ca. 4 % EC (elementary carbon) and ca. 2.8 % OC (organic carbon), all percentages being nearly independent from their position on the street.

As the PM10 component analysis of the PM10 concentrations was done for the measurements in the street and in the background, the additional street concentration could be determined to be 52 % consisting of mineral components (mostly re-suspension and abrasion), 7 % tire wear and 41 % exhaust pipe emission.

Inverse dispersion modelling revealed a total PM10 emission factor of the street between 0.081 and 0.096 g/VKT.

By an alternative, less effort consuming method, using NO_x as a tracer (without dispersion modelling but using the NO_x emissions and the NO_x additional street concentrations) 0.081 to 0.095 g/VKT were found. Thus it was shown, that the two methods yielded nearly the same result in this case.

The total PM10 emissions, determined by inverse dispersion modelling (0.091 to 0.096 g/VKT), are lower than calculated by the EPA formula (0.19 to 0.45 g/VKT, depending on the silt load applied). On the basis of the German Exhaust Pipe Emission Factor Handbook (INFRAS, 1999), an emission of 0.045 g/VKT is determined. Thus the non exhaust pipe contribution in this street for that time period, was roughly the same as the exhaust pipe emission.

By separate analysis of the results during working days and weekends, a separate estimation of the emission factors for trucks and for passenger cars could be done. In this case the emissions of a truck are roughly 25 times the emissions of a passenger car.

The problem of the modification of the emission factors with rain was also addressed. Astonishingly they were not significantly reduced during rainy days, a finding which needs further examination.

3 MODIFIED EPA MODEL (SHORT TERM SOLUTION) AND APPLICATION

3.1 Model

A first modification of the EPA model was done, splitting the emission e into exhaust pipe emission and emission by re-suspension

$$e = e_{\text{exhaust pipe}} + e_{\text{re-suspension}}$$

with re-suspension being defined as contributions from abrasion of the street surface, abrasion of vehicle components (clutch, brakes, tyres) and emission of the dust deposited on the road, which originates from outside the street and which may be crushed by the tires

$$e_{\text{re-suspension}} = e_{\text{street abrasion}} + e_{\text{vehicle component abrasion}} + e_{\text{crushed outside material.}}$$

The exhaust pipe contribution is taken from the German Exhaust Pipe Emission Factor Handbook (INFRAS, 1999). Thus it is depending on the year under consideration, in contrary to the contribution by re-suspension.

Like in the EPA-model, the contribution by re-suspension is considered as dependent on the silt load, the average weight of the vehicle fleet and the number of rainy days. The proposal of the formula is (Gamez et al., 2001):

$$e_{\text{re-suspension}} = a \cdot k \cdot (sL)^{0.52} \cdot W^{2.14} \left[\frac{1}{0.85} \ (1 - 0.5 \cdot r) \right] - e_{\text{exhaust pipe}}(2000) \qquad (1)$$

taking exhaust emission factors of 2000 because the measurements underpinning the parameters in the above formula were made in the year 2000. So, the PM10 emission of a street is $e = e_{\text{re-suspension}} + e_{\text{exhaust pipe}}$(year under consideration) with

$$e_{\text{exhaust pipe}}(2000) = \begin{array}{l} 0.016\ g/km \ \ \textit{for passenger cars (incl. light utility vehicles) and} \\ 0.492\ g/km \ \ \textit{for trucks} \end{array}$$

where:

e= emission factor [g/VKT]

a = correction factor for application in Germany [-]

k = basic emission factor of US EPA = 0.18 g/km

sL = PM75 fraction of the silt load of the street [g/m^2]

W = mean weight of a vehicle of the fleet [t]

r = share of rainy days (precipitation > 0.1 mm per day) during the year, for example r = 0.3 [-] for 122 days of rain per year.

As it has been derived from the EPA formula (EPA, 1997), the above formula should only be used with the mean weight of a vehicle of the fleet as an input. So, it should not be used separately for cars or trucks. The free parameters in the above formular were set as follows:

a) Streets inside cities

According to the measurements, displayed in **Tab. 1** we propose:

a = 0.8 [-] for “good” street surfaces, a = 2 for “bad” street surfaces,

sL= 0.2 g/m^2 for “good” street surfaces, sL = 0.4 g/m^2 for “bad” street surfaces,

and W (car) = 1.1 t W (light utility vehicle) = 1.9 t W (truck) = 9 t.

b) Streets outside cities and motorways

For the application outside cities differences may occur because of different driving patterns and speeds, lack of joining streets, etc.. Despite the lack of monitoring data, we propose as a starting point the following preliminary set of parameters, which were derived on the basis of the results of dust measurements at a motorway in Berlin (Israel et al. 1994) for the years 1989 to 1992 and on additional validity checks:

sL = 0.1 g/m^2,

Outside cities: W (car) = 1.2 t W (light utility vehicle) = 2.0 t W (sNfz) = 11 t,

Motorways: W (car) = 1.3 t W (light utility vehicle) = 2.1 t W (sNfz) = 13 t.

c) Tunnels

Measurements in the tunnel Tegel (Berlin) and Brudermühl (Muenchen) have shown that the PM10 emission by re-suspension in tunnels are lower than in open streets. On the basis of the few known measurements we recommend as a starting point:

car (incl. light utility veh.): $e_{\text{re-suspension}} = 0.025 + e_{\text{exhaust pipe}}$ (year of reference) g/VKT

truck $e_{\text{re-suspension}} = 0.57 + e_{\text{exhaust pipe}}$ (year of reference) g/VKT

The constants were deducted from the PM10 total emissions in the tunnels (0.04 g/VKT für cars and 0.8 g/VKT for trucks) and the PM10 exhaust pipe emissions in the tunnels (0.015 g/VKT for cars and 0.23 g/VKT for trucks).

As this model is mostly based on the EPA approach, it still contains its problems (Venkatram, 2000). Only the annual mean value may be determined in the proposed way, values for single hours might contain even higher errors.

Tab. 1: Measured PM10 emission factors

Author	Year	Monitored Street	Av.Daily Traffic veh/24h	Truck content %	PM10 meassured g/VKT	PM10 calculated g/VKT	Cal-Mon/ Mon in %
LUA Brdbg	1998	Cottbus Bahnhofstr.	23 200	6.7	0.152	0.202	33
LUA Brdbg	1999	Cottbus Bahnhofstr.	27 100	5.6	0.161	0.179	11
LUA Brdbg	1998	Frankf./O Leipz. Str.	34 300	6.2	0.151	0.179	18
LUA Brdbg	1998	Potsd. H.-Thoma-Str.	14 700	4.5	0.120	0.149	24
LUA Brdbg	1999	Potsd. H.-Thoma-Str.	15 200	5.2	0.133	0.161	21
R.-Wulff	1999	Berlin/Frankf. Allee	62 300	4.8	0.126 (0.06-0.140)	0.160	27
Lohmeyer	2000	Berlin/Schildhornstr.	43 200	5.6	0.089 (0.081-0.096)	0.151	70
Israel	94/95	Berlin/Frankf. Allee	54 000	4.0	0.217 (0.159-0.275)	0.162	-25
Lohmeyer	2000	Leipzig/Lützner Str.	26 200	6.5	0.660 (0.470-1.1)	0.684	4
Hüglin	1998	Zürich/Schimmelstr.	27 700	7.9	0.166 (0.142-0.191)	0.222	34
Israel	89-92	Berlin/Lerchpfad	150 000	8.0	0.200 (0.160-0.243)	0.282	41
Israel	1994	Berlin/Tunnel Tegel	37 000	6.0	0.071 (0.063-0.080)	0.103	45
R.-Wulff	1998	Berlin/Tunnel Tegel	40 000	7.0	0.088 (0.069-0.107)	0.100	14
Rabl	1999	M. /Bruderm.-tunnel.	52 000	5.5	0.091 (0.070-0.113)	0.077	-15

A comparison of the measured emission factors in **Tab. 1** with the values, calculated according to the above mentioned method, is displayed in **Fig. 1**. A regression line has been fitted so as to best describe the measured values. It can be seen that the highest value (Lützener Straße in Leipzig) is a lot higher than the rest of the other data with a large gap in between. It also shows, as well as **Tab. 1**, that the parameters were fitted to be conservative, i.e. the calculated emission factor is more likely to be overestimated than underestimated.

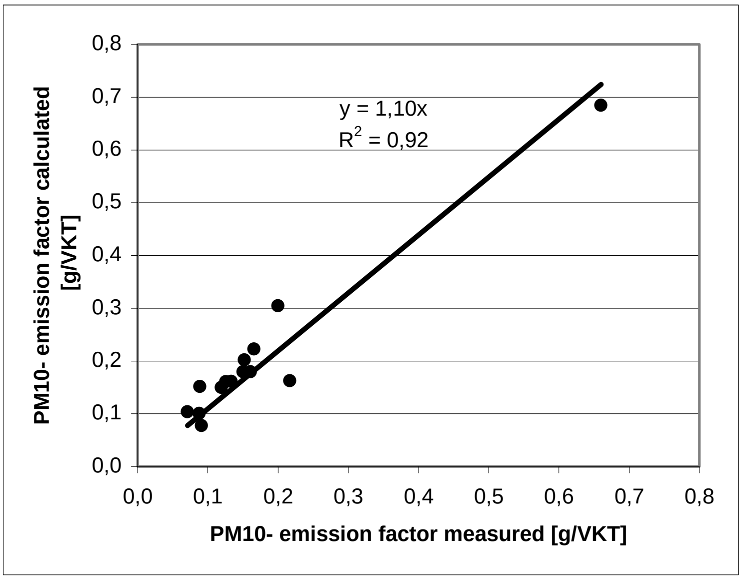


Fig. 1: Calculated (according to eq. 1) and measured emission factors. Without error bars. Note: This is not a validation, as the measured data were used for the development of the calculation method.

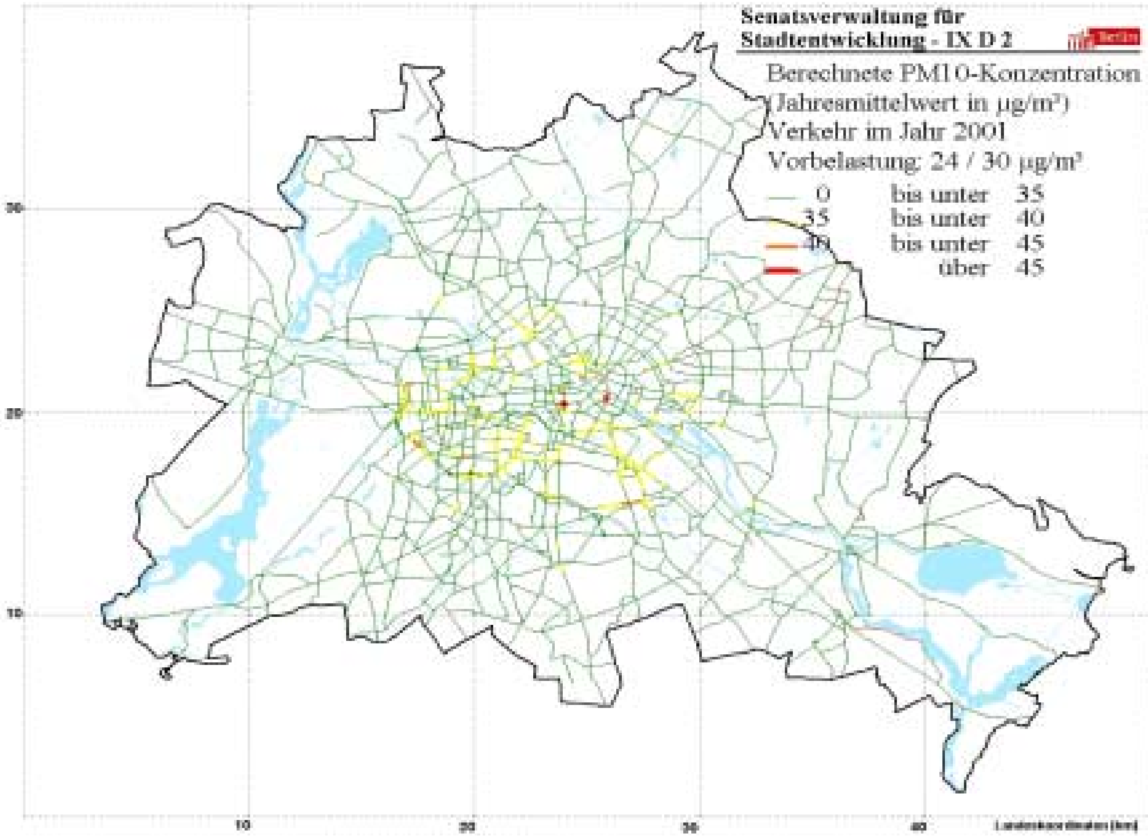
3.2 Application of the model

The model was applied in the above mentioned way to calculate the PM10 concentrations at the kerbside of the main road network of Berlin for the year 2001 with a slight modification in the formula for the PM10 emission factor. As mentioned before, the comparison of measured and calculated PM10 emission factors in **Tab. 1** shows an overestimation of the calculated emission factor by 30 – 40 %. Therefore the correction factor "a" was reduced from 0.8 to 0.5 for the Berlin case. The results show an exceedance of an annual mean PM10 value of 40 µg/m³ in only 11 of the 7500 streets in Berlin (see **Fig. 2 top**). However, the 35th highest daily mean above 50 µg/m³ PM10, which will be the second EU-limit value, is exceeded in about 1/3 of the main roads. See **Fig. 2 bottom**.

Additionally, long term kerbside measurements have been done in Berlin for 3 locations. Their results for the year 2001 are displayed in **Tab. 2**. These observations seem to match the calculated concentrations satisfactorily for practical purposes under the present uncertainties in the calculation of the PM10 emissions.

Tab. 2: Results of PM10 concentration measurements (µg/m^3) in Berlin for the year 2001

Monitoring Station	Annual Mean	90.4%
Autobahn am Funkturm	35	58
Schildhornstraße	33	54
Frankfurter Allee	35	60



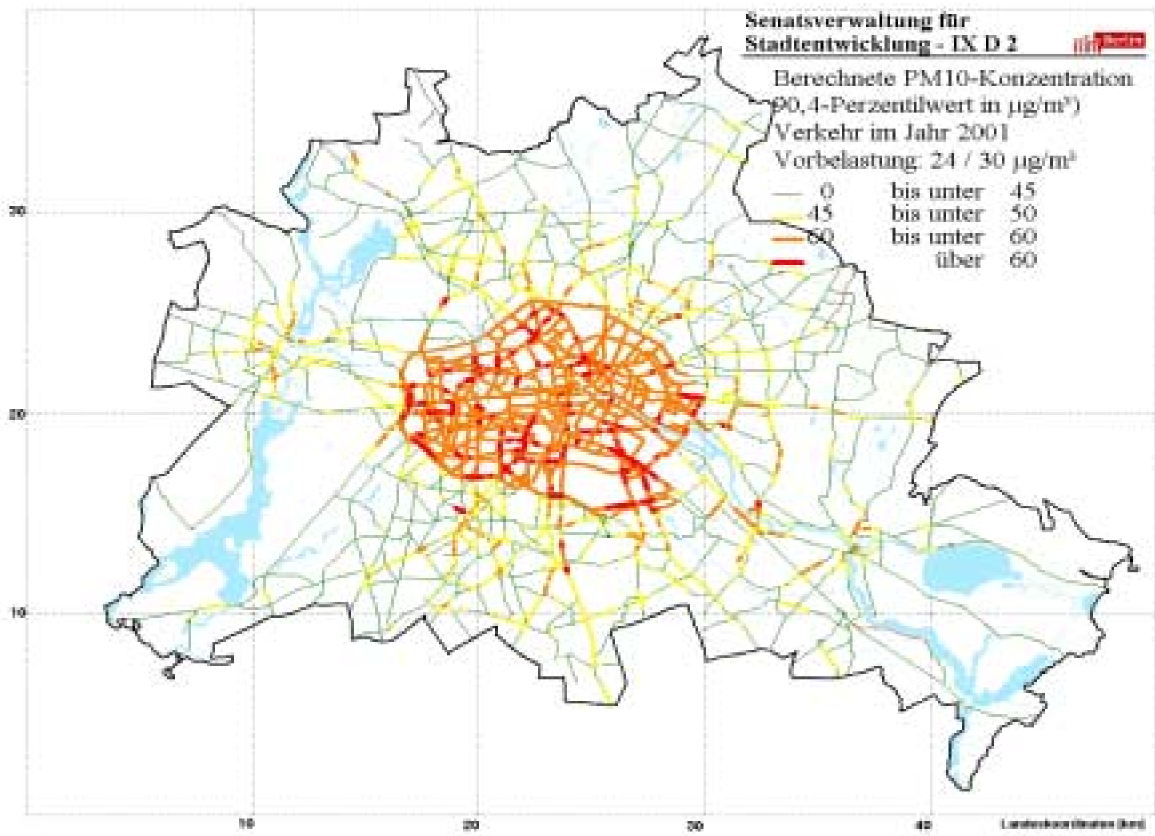


Fig. 2: Calculated PM10 concentrations at the kerbside of the main road network of Berlin for the year 2001. Top: Annual mean. Bottom: 35th highest daily mean. Large scale background concentration 24/30 µg/m³. ("bis unter" means "to below")

4 OPEN TASKS AND MORE PROMISING PROPOSAL

Although we do not yet have enough data at this moment, we propose to discuss a model for heavily trafficked paved streets including the following input parameters:

- Materials of the street surface (asphalt, for example, has a larger abrasion than concrete) instead of the silt load,
- State of the street (new, old, porous, smooth, rough, patched, cracked, weather beaten etc.) instead of the silt load,
- Driving pattern, vehicle speed, ADT etc.,
- Local conditions of rain and humidity.

More investigations are needed, as well as communication input from street maintaining civil engineers. More experiments have to be designed to determine the relevance of the above mentioned parameters and which will allow to find other possible parameters governing PM10 emission. There is especially a lack of measurements at open country motorways with high speed driving patterns.

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